Hawaii Regional Sediment Management: Regional Sediment Budget for the Kekaha Region of Kauai, HI

Edited by Jessica H. Podoski

PURPOSE. This Coastal and Hydraulics Engineering Technical Note (CHETN) reviews the development of a regional sediment budget for the Kekaha Region on the Island of Kauai, HI, as part of the Hawaii Regional Sediment Management (RSM) initiative funded by the US Army Corps of Engineers (USACE) RSM Program. This document discusses the methodology used for determining sediment transport rates, and presents final rates for each littoral cell. The rates presented were used to create the present-day sediment budget for the Kekaha Region using the Sediment Budget Analysis System (SBAS) software.

BACKGROUND. RSM refers to the beneficial use of littoral, estuarine, and riverine sediment resources in an environmentally effective, operationally efficient, and economically feasible manner. The principles of RSM change the focus of engineering activities from the local or project-specific scale to a broader scale defined by the natural sediment processes. A prime motivator for implementing RSM principles and practices in Federally authorized navigation, storm damage reduction, and environmental restoration projects is their potential to reduce construction, maintenance, and operation costs, and to positively impact projects' ability to meet their authorized purposes.

The overall RSM strategy of the US Army Engineer District, Honolulu (POH), is to investigate RSM opportunities along all shoreline regions in Hawaii. Initial RSM regions on Kauai include the Kekaha Region and the Poipu Region on the west and south shores of the Island, respectively (Figure 1). This CHETN pertains to the Kekaha Region only. The Poipu Region is addressed in Podoski (2013a). The Kekaha Region contains a Federal navigation project (Kikiaola Light Draft Harbor), a Federal flood control project (Waimea River), and a Federally co-sponsored shore protection project (Kekaha Beach). The preliminary Kauai RSM strategy (Moffatt and Nichol 2011) provides detailed background on these Federal projects, defines the objectives of the investigations, describes the geomorphological setting, and quantifies coastal processes within both these regions.

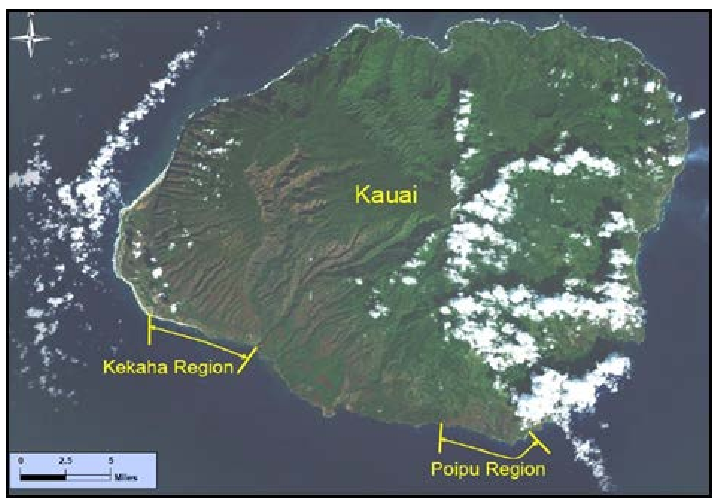

Figure 1. Initial RSM efforts on Kauai concentrated on the Kekaha Region and Poipu Region.

KEKAHA REGION. The Kekaha Region is bounded on the east by the Waimea River and extends 6.3 miles to the west to Kokole Point. The four littoral cells that define the Kekaha Region

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shoreline [(1) Waimea, (2) Kikiaola Harbor, (3) Oomano Point, and (4) Kekaha Beach] are shown in Figure 2. The four littoral cells are distinctly different. The Waimea River discharges upland sediment that is predominately distributed west along the Waimea cell that is bounded by the eastern jetty of Kikiaola Harbor. Waimea Beach has accreted since completion of Kikiaola Harbor. A small amount of sand may move out of the cell to the east of the Waimea River. Some sediment passes from the Waimea cell to the west and is deposited in the Kikiaola Harbor entrance channel and basin. Upland sediment also enters the Harbor, and Harbor dredging was performed in 2007-2009. For these reasons, Kikiaola Harbor is considered its own littoral cell.

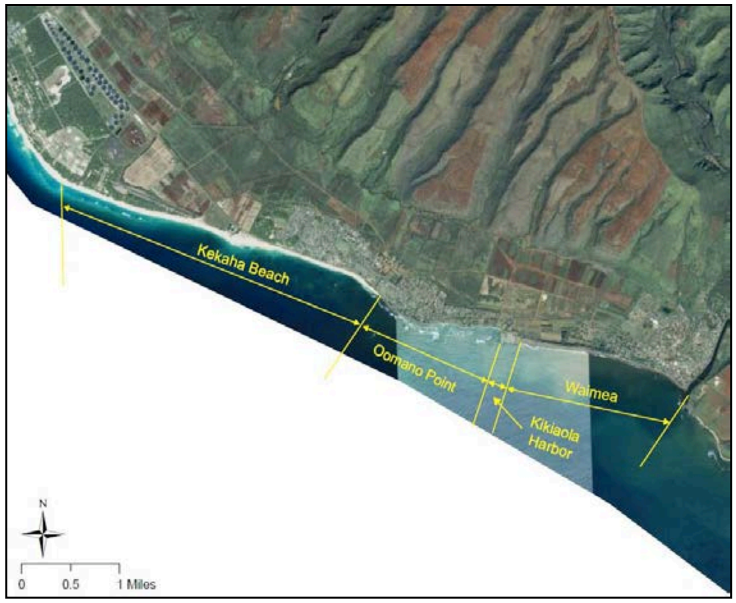

Figure 2. Littoral cells in the Kekaha Region of Kauai.

The neighboring Oomano Point cell extends from Kikiaola Harbor to a rocky headland near Oomano Point, and the shoreline is primarily terrigenous sediment. Sediment exchange between the Kikiaola and Oomano cells appears to be minimal, and the Kikiaola Harbor structures effectively inhibit sediment exchange that previously occurred between Waimea Beach and Oomano Beach. The rocky headland marks the transition between the Oomano Point and Kekaha Beach cells, and the two cells jointly contain 10,850 ft of continuous revetment (Moffatt and Nichol 2011) of which 6,250 ft consists of the Federally authorized Kekaha Storm Damage Reduction Project. Erosion at the western end of the revetment threatened the adjacent coastal highway. The Hawaii Department of Transportation consequently installed a pile dike along the impacted portion of highway to prevent undermining. The Kekaha Beach cell is the longest cell in the region and is part of a long stretch of predominately calcareous sand beach. The distinct difference in sediment composition suggests that there is no sediment exchange between the Oomano Point and Kekaha Beach cells. The beach widens toward Kokole Point, which marks the western boundary of the cell and region.

APPROACH. The RSM approach outlined here applies equally to both the Kekaha Region and the Poipu Region of Kauai. The initial phase of RSM investigations in the Kekaha Region included the quantification of volume changes inferred through a shoreline change analysis. Shoreline erosion maps, including shoreline position change rates (as derived from historical aerial photographs) along much of the study regions, have been developed by the University of Hawaii Coastal Geology Group (UH CGG) (Fletcher et al. 2012) for the US Geological Survey (USGS) as part of the USGS Coastal Hazard Mapping program. The historical volumes of sediment on the beaches were estimated based on these rates, using a conversion factor for volume of 0.40 cubic yards per square foot (cu yd/sq ft) of beach area gained or lost. This factor is based on the results of beach profile analysis recently conducted along the south coast of Oahu (Diamond Head to Pearl Harbor RSM strategy). The factor

of 0.40 cu yd/sq ft is analogous to a beach with a crest-to-toe elevation difference of about 11 ft. Ideally, detailed beach profile surveys and/or nearshore bathymetric surveys would be used to verify and further refine the calculations for each cell.

The Kauai RSM strategy (Moffatt and Nichol 2011) described historical beach volume changes for each of the littoral cells in the Kekaha Region from the early 1900s up to 2006. An average volume change rate over the entire time period of shoreline records was also calculated for each littoral cell. The beach sediment change rates are complicated by trend (accretion/erosion) reversals, historic shoreline structures, and seasonal effects. These were taken into account where possible.

This CHETN focuses on the creation of a sediment budget using the most recent shoreline change data available. Shoreline change rates were therefore calculated for the most recent digitized shorelines available from the UH CGG (Fletcher et al. 2012). Historical shorelines used were 1966, 1992, and 2006 for the Kekaha Region. For each cell, the shoreline change was measured at 20-m (~65-ft) intervals alongshore. Shoreline change figures totaling annualized volumetric change were produced. Discrete shoreline change within each cell was used to identify localized areas of shoreline change. This can assist in inferring the sediment transport patterns. The calculated annualized volumetric change rate for each cell provides the basis for creating the sediment budget.

Similar sediment budget analyses were performed for the Kihei and Kahului Regions of Maui (Podoski 2013b) using wave model results to infer longshore sediment transport potential. Wave height, period, and direction parameters obtained from selected stations within the US Army Engineer Research and Development Center (ERDC) Wave Information Study (WIS) (Hubertz 1992) hindcast dataset were used as input to the model STeady WAVE (STWAVE) (Smith et al. 2001). The model output provides nearshore wave heights and directions at intervals along the shoreline. These model results were used to calculate sediment transport rates using the commonly known “CERC formula” (USACE 2003).

Similar modeling was performed for the Kauai RSM strategy. Details are presented in Moffatt and Nichol (2011). Wave modeling was performed using a 50-m (~165-ft) grid spacing that is quite coarse and tends to significantly smooth the nearshore bathymetric features that are important in accurately resolving the nearshore wave heights and directions, which in turn are the inputs to the sediment transport calculations. The CERC formula that was used in the Kihei and Kahului Regions (Podoski 2013b) includes an empirical coefficient (K) used to calibrate the formula for the local area.

In the present effort, attempts were made to calibrate the CERC formula in the controlled area of Waimea Beach for the years 1966-1992, which is the only cell where reliable longshore transport estimates based on shoreline change could be made. The resulting K value was found to be 0.126, approximately one-third of the 0.39 value recommended in the *Coastal Engineering Manual* (USACE 2003) and substantially larger than the 0.001 to 0.009 range used for Maui (Podoski 2013a). The CERC formula was then applied to the eastern half of the Kekaha Beach cell using nearshore modeling data as input. The results showed that 62% of the transport for a net of 8,050 cu yd/yr is toward the east, into an area shown (in the “Kekaha Beach cell” section below) to be highly eroding. Additionally, the modeling results show that 33% of the sediment transport would be toward the west from Oomano Point, which would result in transport of terrigenous sediment onto a beach that is highly calcareous. Meaningful amounts of terrigenous sediment, however, are not found on Kekaha Beach.

The model results were therefore deemed to have no practical applicability to the littoral cells in the Kekaha area. Of the four littoral cells in the Kekaha Region, only the western boundary of the Kekaha cell can be considered open. Estimation of sediment transport rate at that cell was unsuccessful for reasons stated in the "Kekaha Beach cell" section below.

KEKAHA REGION SEDIMENT BUDGET.

Waimea cell. The Waimea River is the major input to the littoral cell, as is apparent from the terrigenous sediment that composes Waimea Beach. The dynamics of Waimea Beach and Oomano Beach were greatly altered by the construction of Kikiaola Light Draft Harbor in 1959. The sediment input from the Waimea River has not been directly measured. This sediment input, however, can be estimated by determining the amount of sediment impounded on Waimea Beach east of the harbor immediately after the harbor was constructed, but before the accretion exceeded the retention capacity of the harbor east jetty. Analysis of the 1966 and 1992 shorelines indicates that Waimea Beach accreted at an average rate of 10,709 cu yd/yr during that time period (Figure 3). This provides a reasonable estimate of Waimea River input. More recently, as the shoreline continued to accrete and the impoundment capacity of the harbor was reached, some sediment was transported west from Waimea Beach into Kikiaola Harbor. The 1992 and 2006 shorelines were used to determine the more recent rate of accretion of 7,341 cu yd/yr (Figure 4). Assuming that the average annual influx of sediment from the Waimea River has remained constant and is represented by the 1966-to-1992 rate of 10,709 cu yd/yr, the difference in the accretion rates is interpreted as the amount of sediment leaving the Waimea Beach cell into the Kikiaola Harbor cell. This amounts to about 3,400 cu yd/yr.

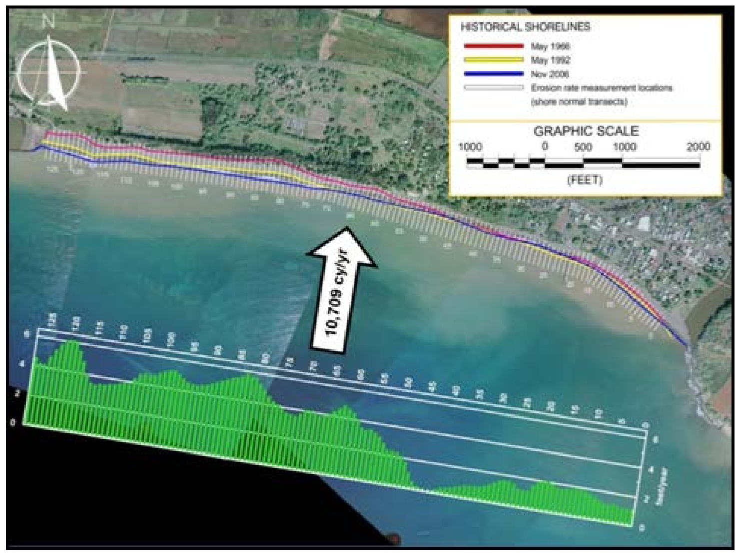

Figure 3. Waimea cell shoreline change rates and sediment budget, 1966-1992.

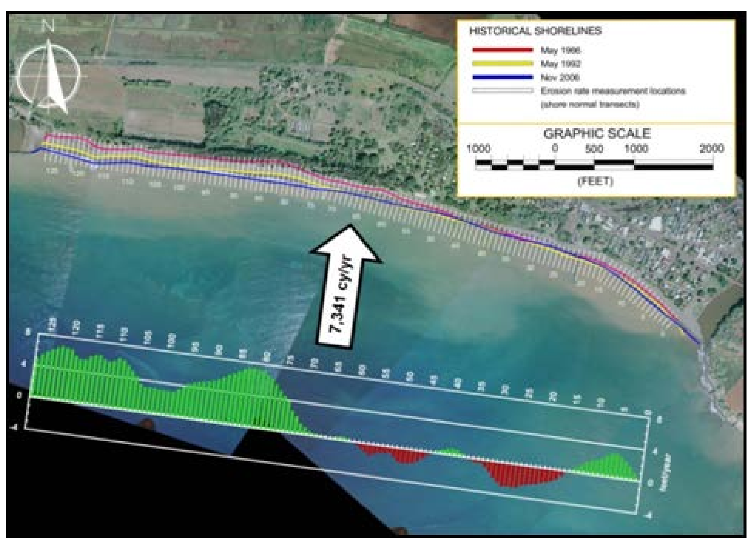

Figure 4. Waimea cell shoreline change rates and sediment budget, 1992-2006.

Kikiaola Harbor cell. Dredging of Kikiaola Harbor was completed in 2009, and included dredging the 700-ft-long entrance channel to -11 ft mean lower low water (mllw), an interior access channel to -7 ft mllw, and an interior turning basin and dock approach to -7 ft mllw. The sedimentation rate in the harbor was estimated by comparing harbor bathymetry data collected by the USACE in July 2012 with the design dredge depths. This preliminary comparison indicated that approximately 5,000 cu yd/yr of material had accumulated in the harbor and entrance channel. Kikiaola Gulch contributes approximately 1,600 cu yd of this material (Moffatt and Nichol 2011). This suggests that approximately 3,400 cu yd of the sediment is transported from outside the harbor, which is consistent with the estimated sediment contribution from the Waimea cell described above. A detailed analysis to quantify the rate of shoaling and infilling of the harbor since it was dredged in 2009 has now been conducted.

Oomano Point cell. The construction of Kikiaola Harbor has effectively blocked any sediment exchange between the Waimea cell and the Oomano Point cell, which is eroding at a rate of 4,935 cu yd/yr based on the 1992 and 2006 shorelines (Figure 5). Between 1998 and 2001, a total of 15,000 cu yd of sand was removed from Waimea Beach and placed on Oomano Beach (Moffatt and Nichol 2011). Channel dredging from 2007-2009 removed an estimated 30,000 cu yd of material from the harbor. The balanced sediment budget at Kikiaola Harbor, along with the sediment-starved Oomano Beach immediately adjacent to the harbor, suggests that there is no sediment exchange between the Kikiaola Harbor cell and the Oomano Point cell. At the west end of the cell, the terrigenous sediment ends and a rocky headland emerges.

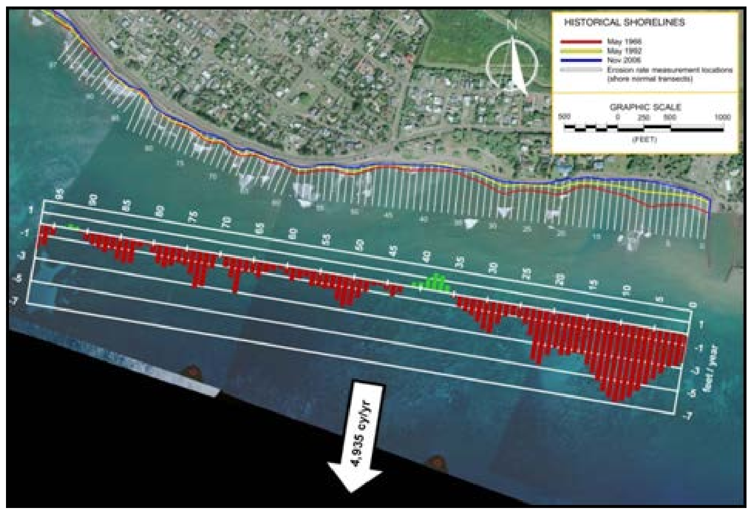

Figure 5. Oomano Point cell shoreline change rates and sediment budget, 1992-2006.

Kekaha Beach cell. Beyond the rocky headland at Oomano Point, the shoreline sediment is predominately calcareous. The remarkably different sand characteristics on opposite sides of the headland lead to the conclusion that there is no sediment exchange between the Oomano and Kekaha Beach cells. Based on the 1992 and 2006 shorelines, Kekaha Beach is eroding at 21,842 cu yd/yr (Figure 6). The western end of the Kekaha cell, and the Kekaha study area as a whole, is at Kokole Point. Although the study area ends there, the sand beach is continuous, and this is not necessarily a littoral boundary. Kekaha Beach faces south-southwest and is generally exposed to southern swell and refracted trade wind waves. The beach west of Kokole Point is oriented to face more west-northwest, and is exposed to both southern and northern swell. This difference in shoreline orientation appears to be sufficient to produce different driving forces and different shoreline dynamics.

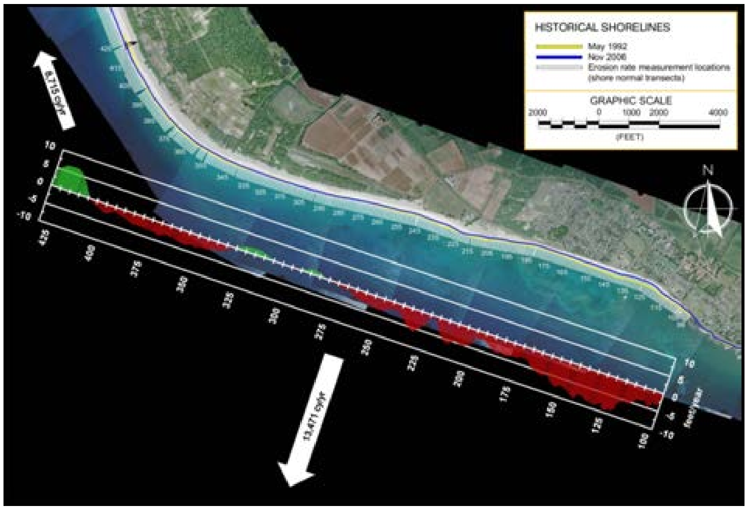

Figure 6. Kekaha Beach cell shoreline change rates and sediment budget, 1992-2006.

The present shoreline analysis shows the Kekaha cell to be eroding at a rate of nearly 22,000 cu yd/yr for the years 1992 to 2006. While interpretation of Figure 7 suggests that there is substantial offshore transport, the sand beach continues from Kekaha Beach, around Kokole Point, and past Majors Bay. It is likely that there is longshore transport at the western boundary of the Kekaha Beach cell. Qualifying and quantifying the sediment transport at the western boundary of the Kekaha cell is challenging. The closest nearshore save point produced by the wave modeling in the Kauai RSM plan (Moffatt and Nichol 2011) is 10,000 ft to the east. This is not close enough to translate into meaningful results at Kokole Point. The Kokole Point shoreline change map study produced by UH CGG (Fletcher et al. 2012) states that Kokole Point has been historically stable; however, analysis of more recent shorelines has shown Kokole Point to be eroding at an annualized rate of up to 4 ft/yr. To the north of Kokole Point, the shoreline straightens for 5,450 ft. The southern portion of this shoreline accreted from 1992 to 2006 at rates of 4 to 6 ft/yr (Figure 7). Unfortunately, the 1992 shoreline does not extend further toward Majors Bay. Assuming conservatively that the rate of shoreline change along this shoreline reach is 4 ft/yr, the resulting average transport rate out of the Kekaha Beach cell towards Majors Bay would be 8,715 cu yd/yr. Further studies are required to more thoroughly describe the sediment transport at Kokole Point. There may be seasonally-directional sediment transport past Kokole Point; however, seasonal trends cannot be identified in this data set.

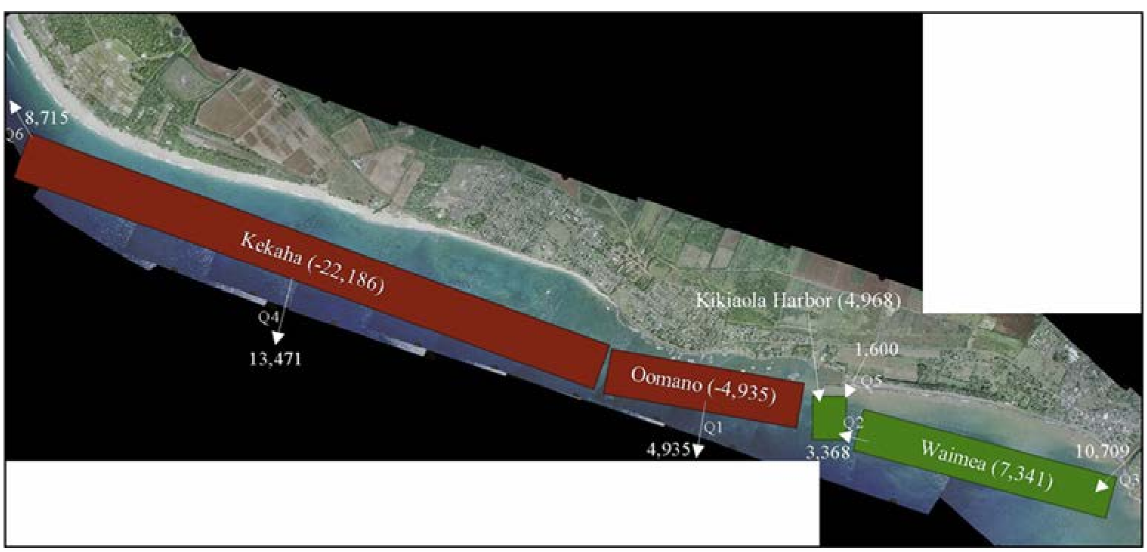

Figure 7. Sediment budget for Kekaha Region, developed using the Sediment Based Analysis System (SBAS) (cu yd/yr).

Table 1 summarizes the shoreline change rates for the Kekaha Region. The right-hand column contains the accretion/erosion rates calculated in the present study, while the middle two columns contain the rates presented in the Kauai RSM strategy (Moffatt and Nichol 2011).

Table 1. Kekaha Region Long-term and Short-term Volume Change Rates.

Littoral Cell	Accretion(+)/Erosion(-) Rate Over Entire Period of Record, cu yd/yr*	Accretion(+)/Erosion(-) Rate Over Recent Period, cu yd/yr*	Accretion(+)/Erosion(-) Rate Over 1992-2006 Period, cu yd/yr
Waimea	+8,300	+10,650	+7,341
Kikiaola Harbor	—	+600 to +3,000	+5,000
Oomano Point	–5,100	–4,200	–4,935
Kekaha Beach	–7,100	–20,500	–21,842
Source: Moffatt and Nichol (2011).			

SEDIMENT BUDGETS USING SBAS. The final step in the sediment budget process was the use of the Sediment Budget Analysis System (SBAS) software for ArcGIS©10 toolbar (Rosati and Kraus 2001, Dopsovic et al. 2002) in combination with the sediment budget equation (Equation 1) to finalize cell balancing calculations, and to visually illustrate the calculated transport rates and directions as shown in Figure 7. The sediment budget equation is expressed as:

$$\Sigma Q_{source} - \Sigma Q_{sink} - \Delta V + P - R = \textbf{Residual} \tag{1}$$

where:

Q_{source} = sediment transport rate into the cell
Q_{sink} = sediment transport rate out of the cell
ΔV = volumetric change rate within the cell
P = artificially-placed sediment rate in the cell
R = artificially-removed sediment rate from the cell.

Residual in Equation 1 indicates the balancing of the cell (negative = eroding, positive = accreting, zero = balanced).

Each of the terms above has the units of volume per unit time (i.e., cu yd/yr), and the P and R terms represent regular maintenance activities such as dredging, bypassing, or nourishment. The region addressed in this study has experienced one or more of these activities, although not on a regular basis. This present study which produced the present-day sediment budget did not take into account such occasional placement or removal of sediment.

PRACTICAL APPLICATION OF SBAS FOR DEVELOPMENT OF REGIONAL SEDIMENT BUDGETS. The ability to create a visualization of the calculated RSM sediment budget for the Kekaha Region using SBAS toolbar within ArcGIS©10 helped to refine the preliminary sediment budget and provided an invaluable communication tool for discussions with sponsors and stakeholders of the RSM program. The use of SBAS to generate sources, sinks, and flux rates was key in the process of balancing littoral cells for this application. Using SBAS within ArcView allows the user to overlay littoral cells and sediment pathways onto an aerial photo of the

region, which helps to convey a practical understanding of how sediment movement occurs in the nearshore and of how exchanges occur between cells in the overall region. Although not used in this application, the ability to integrate other data (such as shoreline change data or bathymetry) directly into ArcGIS could also prove highly valuable in development of the sediment budget by refining volume and flux numbers based on this additional spatial data.

The accuracy of a regional sediment budget and its subsequent ability to adequately capture shoreline dynamics depends on the quality of the input data. The input data used in both the Kauai RSM strategy (Moffatt and Nichol 2011) and this study were historical shorelines produced by the UH CGG. The UH CGG recent shorelines are typically separated by a number of years. These shorelines were developed based on available aerial photographs which were not necessarily taken at the same time of the year. However, most of Hawaii's shoreline locations are seasonally dependent; frequent sampling is necessary to discern short-term seasonal responses from long-term trends. To capture (and remove) the seasonal effects, more frequent sampling would be necessary.

The Kauai RSM strategy (Moffatt and Nichol 2011) and this present study assume that 1.0 sq ft of beach change equates to 0.40 cu yd of material volume. This factor was developed for the Oahu Diamond Head to Pearl Harbor RSM strategy and is tentatively applied to the present project. The factor is a function of beach crest and toe elevations and can change from one beach to another beach. Profile analysis can help to determine the proper factor for each cell.

The use of shoreline change data to infer sediment transport characteristics requires a good working knowledge of the local dynamics. Experience with the individual cells was used whenever possible. Cross-shore sediment transport rates are difficult to calculate, and cross-shore transport patterns have been determined based on inferred local shoreline dynamics. As a result, a few quantities were estimated in order to balance the budget where applicable.

All of these points add uncertainty to the sediment budget calculations, and this uncertainty will exist until more data are available.

CONCLUSIONS. This CHETN has provided a brief overview of the development of a regional sediment budget in support of RSM activities on the Island of Kauai, HI. A present-day sediment budget for littoral cells in the Kekaha Region was developed based on historical shoreline data provided by the University of Hawaii Coastal Geology Group (Fletcher et al. 2012). Many of the cells in the Kekaha Region were closed to longshore transport, primarily by rocky headlands. The historical shoreline positions contain a level of uncertainty and cannot account for seasonal variation in the beaches. Additionally, sea level rise was not taken into account as a cause of shoreline recession.

Application of the CERC formula to estimate longshore sediment transport rates was attempted for the littoral cells of the Kekaha Region. Calibration of the K coefficient was possible only at the Waimea Beach cell of the Kekaha Region. The Waimea Beach cell consists of primarily terrigenous sediment. Use of this coefficient K at the other cells with calcareous beaches may not be valid and, when the CERC formula was used, it showed significant longshore transport into an area that is shown by the shoreline change analysis to be eroding. This was also confirmed by the wave model results which contain a directionality factor. For these reasons, and also because most of the cells of the Kekaha Region are closed, the CERC formula was not used. Sediment transport rates and sediment budgets may be refined as the result of more detailed measurements.

The wave modeling results could be improved by using offshore data results based on a spectral model that can resolve multiple wave trains occurring simultaneously. The WIS data is parametric, and this shows only peak energy from one wave train.

ADDITIONAL INFORMATION. This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared by Sea Engineering, Inc., Waimanalo, HI, for the US Army Engineer District, Honolulu (POH), Honolulu, HI, as part of the Hawaii Regional Sediment Management (RSM) initiatives funded by the USACE RSM Program. Editorial revisions were provided by Jessica H. Podoski, POH. Additional information pertaining to the RSM Program can be found at the RSM website http://rsm.usace.army.mil

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ACRONYMS AND ABBREVIATIONS.

Term	Definition
CERC	Coastal Engineering Research Center
CHETN	Coastal and Hydraulics Engineering Technical Note
CHL	Coastal and Hydraulics Laboratory
ERDC	Engineer Research and Development Center
POC	Point of Contact
POH	US Army Engineer District, Honolulu, HI
RSM	Regional Sediment Management
SBAS	Sediment Budget Analysis System
SR	Special Report
STWAVE	STeady WAVE (numerical model)
UH CGG	University of Hawaii Coastal Geology Group
US	United States
USACE	US Army Corps of Engineers
USGS	US Geological Survey
WIS	Wave Information Study